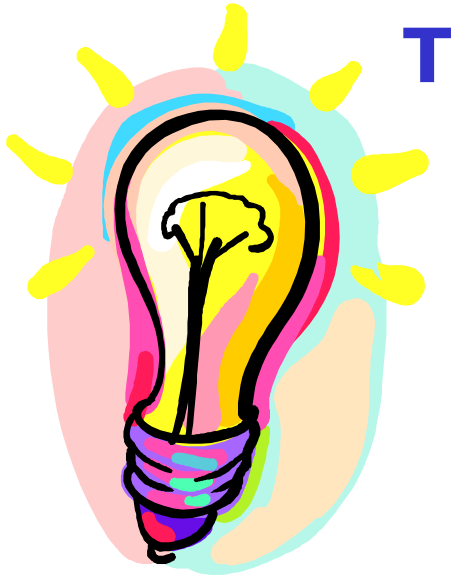
Assessments of Trends in Condition Monitoring Systems and Life Cycle Cost Management for Combined Cycle Power Plants



Turbine Power Systems Conference And Condition Monitoring Workshop

The Boyce Consultancy

Present New Advanced Gas Turbine

High Thermal Efficiency—40% - 45%

Lower Availability (up to 10% Lower)

Lower Life of Nozzles and Blades (averaging 15000 hrs)

Higher Degradation Rate (5% - 7% in first 10,000 hours of operation)

Instability of Low NO_x Combustors

OPERATION OF COMBINED CYCLE POWER PLANTS

- NO LONGER BASE LOAD OPERATION
- DAILY CYCLING OF POWER LOAD
- PLANTS SHUT DOWN OVER WEEKENDS

The **Availability** of a power plant is defined as

$$A = \frac{P - S - F}{P}$$

where:

P = Period of time, hours, usually this is assumed as one year, which amounts to 8760 Hrs.
S = Scheduled outage hours for planned maintenance
F = Forced outage hours or unplanned outage due to repair.

The Reliability of a power plant is defined as

$$R = \frac{P - F}{P}$$

IMPROVEMENT OF RELIABILITY AVAILABILITY AND MAINTAINABILITY

TOTAL CONDITION MONITORING

- PERFORMANCE BASED MAINTENANCE
- OVERHAUL BASED ON MONITORING
- SPECIAL LOW NO_x COMBUSTION MONITORING
- PYROMETER, OR OTHER TYPE OF DIRECT MEASUREMENT SENSORS FOR BLADE METAL TEMPERATURES TO IMPROVE BLADE LIFING

RAM

IMPROVEMENT IN RAM HAS MANY BENEFITS TO THE U.S. OVERALL ENERGY PROGRAM

- If the availability in California was up by 2% there would have been very few if any brownouts. This is due to an increase in available Power by more than 300 MW.
- Reduction of CO_2, would occur as a direct function of fuel savings. A 2% in fuel savings would reduce the amount of CO_2 being emitted by the same percent.
- Reduction of other Pollutants

RAM

IMPROVEMENT IN RAM HAS MANY BENEFITS TO THE U.S. OVERALL ENERGY PROGRAM

- Fuel savings (operating the turbine as close to its design efficiency). A 1% reduction in degradation could amount to a savings of 400 million gallons of oil per year,based on a power consumption of 70.1×10^4 GWh.
- The 2.7 c/ kWh amounts to a 20 % reduction in costs. This takes into account fuels savings, and operation and maintenance savings. Fuel cost is based on $7.0 MBTU

RAM

IMPROVEMENT IN RAM HAS MANY BENEFITS TO THE U.S. OVERALL ENERGY PROGRAM

Total Emissions of a typical unit by Weight

UHC = 0.05%

CO = 0.1%

NO_x = 0. 35%

CO_2 = 99.5% (3.14x Fuel Flow)

PHASE 1

- Obtain accurate information from plants to determine the major problems of the new Gas Turbine Combined Cycle Power Plants.
  - Type of Failures
  - Heat Rate Degradation
  - Power Degradation
  - Correlation with Fuel Types
- Obtain accurate information of Condition Monitoring Systems available at present
  - Type of Data Gathering System
  - Instrumentation Used and Needed
  - Analysis Ability
  - Prognostic Ability

GOALS OF CONDITION MONITORING

- Ensuring High Machine Availability and Reliability
- Maintaining peak efficiency and limiting performance degradation of machine trains
- Extending time between inspections and overhauls
- Optimizing the cycle configuration
- Estimating Availability
- Evaluating scenarios by means of “What If” Analysis
- Estimating maintenance requirements and life of hot section components
- Fault identification by Expert System analysis.

MAJOR COMPONENTS OF A CONDITION MONITORING SYSTEM

- AEROTHERMAL ANALYSIS
- COMBUSTION ANALYSIS
- VIBRATION ANALYSIS
- MECHANICAL ANALYSIS
- DIAGNOSIS
- TRENDING AND PROGNOSIS
- WHAT - IF

CONDITION MONITORING

- Present systems serve mostly a monitoring function.
- Monitoring of combustion systems for Low NO_x Combustors a very important need which needs to be addressed
- Lifing Algorithms a very important need that remains unfulfilled.

Survey of Users

- Gas Turbine Users Conference - Banff Canada
- IGTI Expo and Conference – New Orleans
- Independent Power Plants
- Various Petrochemical Plants

Users

- Most Users want a Condition Monitoring System
- Limited Condition Monitoring Systems in Use
- On- Line Compressor wash widely used
- Shaft Vibration Systems in Most Plants
- Exhaust Gas Temperature Analysis Widely Used

Major User Concerns

- Reduction in Availability and Reliability
- Repair of Single Crystal Blades
- Low NO_x Combustors
- Surge in Compressors
- Bearings and Seal Problems

Survey of Manufacturers

- Gas Turbine OEM's
- Condition Monitoring Equipment
- Repair Facilities

Manufacturers

- Change in Philosophy due to Operation and Maintenance Contracts
- Limited Condition Monitoring Equipment Supplied with Equipment
- New Instruments
- New Techniques

Survey of Research Agencies

- EPRI
- NASA
- DOD
- KEMA-The Netherlands
- DERA-The UK

Research Agencies

- New Techniques in Monitoring
  - Statistical Analysis
  - Neural Networks
- New Instrumentation
  - Pyrometers-Metal Blade Temperatures
  - Dynamic Pressure Transducers
  - Surface
- Diagnostics
- Life Cycle Analysis

GOALS

NEXT GENERATION TURBINE PROGRAM

IMPROVEMENT OF RELIABILITY, AVAILABILITY AND MAINTAINABILITY

15 % OR HIGHER REDUCTION ON O&M COSTS

LIMIT DEGRADATION TO 2%/ yr

FLEXIBILITY OF 400 STARTS PER YEAR

MULTIPLE FUEL FLEXIBILITY

15 % OR HIGHER REDUCTION OF O&M COSTS

- ON-LINE CONDITION MONITORING
- LIMIT DEGRADATION to 2%/YR
- OPERATE AT HIGH EFFICIENCY CONDITIONS AT OFF-DESIGN OPERATION
- IMPROVE COMPONENT LIFE (25,000 hrs)
- INCREASE TIME BETWEEN MAJOR OVERHAULS (8,000-12,000 hrs)

FLEXIBILITY OF 400 STARTS PER YEAR

- ESTIMATION OF STRESS AND EQUIVALENT OPERATING HOURS
- STEAM TURBINES LIMITING PARAMETER IN COMBINED CYCLE POWER PLANTS

MULTIPLE FUEL FLEXIBILITY

NATURAL GAS AS BASE LINE

- Price of Natural Gas North of $7.0/MBTU's
- Alternative Fuel Strategy

- Low BTU Gases
  - Coal Gasification
  - Land Fill
- FUEL TREATMENT
- FUEL TRACING AND SPECIAL DESIGN FOR HEAVY FUELS
- ON-LINE TURBINE WASH

PHASE II

- Obtain information regarding new instrumentations that have been developed by various government agencies:
  - Department of Energy
  - NASA
  - Department of Defense
- Obtain information regarding new analytical techniques available:
  - New Techniques Of Data Validation
  - Training Patterns
  - Neural Networks
  - Fuzzy Logic

Condition Monitoring Workshop

- Performance
- Diagnostics
- Combustion Stability, Emissions, and Related Controls Issues
- Instrumentation Instrumentation
- Data Validation
- Hot Section Lifing: Optimal Maintenance Interval Timing

CONDITION MONITORING SYSTEMS

- Mechanical and Performance Based
- Data Validation
- Aero-Thermal Performance Based Models
- Stress Dynamics with Loading & Temperature
- Rotor Dynamics
- Combustion Stability Analysis
- Trending and Prognostics
- Diagnostics and Expert Systems
- Lifing Prediction
- Optimization Studies

TECHNICAL ISSUES

- Data Validation
- Development of New Instrumentation
- Development of Lifing Algorithms for Various Hot Section Components
- Development of Diagnostic Matrix
- Development of Optimization Programs for Combined Cycle Plants
- Development of Maintenace Programs based on Condition Monitoring

DATA VALIDATION

- NEW TECHNIQUES OF DATA VALIDATION
- TRAINING PATTERNS
- NEURAL NETWORKS
- FUZZY LOGIC

Development of New Instrumentation

- Blade Metal Temperature Sensors
- On line Monitoring of Ferrous and Non-Ferrous Particles in the Lubrication System
- On-line Monitoring of Exhaust Gases for Metal Particles
- Long Term Dynamic Pressure Transducers for Combustion Monitoring
- Monitoring Low NO_x Combustors

Parameters Effecting Hot Section Life

- Type of fuel.
- Type of Service
- Firing Temperature
- Materials stress and strain properties
- Coatings
- Effectiveness of cooling systems
- Number of starts.
- Number of Full Load Trips.

Development of Lifing Algorithms for Various Hot Section Components

- Algorithms for Single Crystal and Directionally Solidified Blades
- Algorithms for Combustion Liners
- Algorithms for Various Diagnostics

Development of Diagnostic Matrix

- Diagnostic For Various Turbomachines
- Design of an Expert System
- Prognostics
- Diagnostics for Rest of Plant Equipment
- Development of Fuzzy Logic Systems with Algorithms

Development of Optimization Programs for Combined Cycle Plants

- Updating of all Efficiency Curves Based on Data obtained from Condition Monitoring Analysis
- Part Load Optimization of Various Plant Equipment
- Maximizing Efficiency at Off Load Conditions

Development of Maintenance Programs based on Condition Monitoring

- Performance Based Condition Monitoring Maintenance
- Component Lifing Studies
- Major Inspection Intervals based on Total Condition Monitoring

PHASE III

Commercialization Plan
A Program Bringing
Users, OEM, and Instrumentaion Companies Together

- Commercialize new instrumentation for application in gas turbines and the rest of the combined cycle power plant.

- Commercialize techniques of Data Validation, Analytical Techniques, and Diagnostic Techniques